

The gubernaculum during testicular descent in the human fetus

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INTRODUCTION

John Hunter in 1762 was the first to publish a detailed description of the structure which “connects the testis with the scrotum and directs its course in its descent”, and which he named the gubernaculum (Backhouse, 1964). The Latin word gubernaculum means helm or rudder – not helmsman, as supposed by some authors (Peters, 1979; Elder, Isaacs & Walsh, 1982). Over the past two centuries a number of divergent and often conflicting theories have been proposed to explain the mechanism of testicular descent. In general, these theories have held that the testis is either pulled or pushed from the abdomen into the scrotum, or that it reaches its destination by a combination of growth or involution processes.

The traction theories propose that the contraction of striated or unstriated muscle fibres or the contracture of connective tissue intrinsic to or surrounding the gubernaculum acts to pull the testis down (Curling, 1840; Lockwood, 1888; Wyndham, 1943). These theories rest on the assumption that the gubernaculum has firm attachments both cranially and caudally, and up to 6 distal attachments have been described (Hunter, 1926). A related theory is that the gubernaculum is somewhat like an hour-glass shaped bladder passing through the inguinal canal, and that the contraction of muscle fibres around its intra-abdominal portion causes this to be shoved into the scrotal part (Weber, quoted by Cleland, 1856). Another theory proposes that the gubernaculum is similar to a balloon with its fundus dilating outside the confines of the inguinal canal, thus exerting traction on the intra-abdominal testis (Wensing, 1968). The force of gravity has also been considered a causative factor (Hunter, 1841; Sonneland, 1925), and recently it was proposed that peristaltic and secretory activity in the epididymis changes its centre of gravitation, thus causing descent of the epididymis, which carries the testis with it (Hadžiselimović, 1983).

The theories of propulsion suggest that the testis is expelled from the abdomen by the force of increased intra-abdominal pressure, which may be the result of contraction of the abdominal wall muscles, respiratory efforts of the fetus, and the forces of labour (Hunter, 1841), distension of the bowel by meconium (Hunter, 1926), growth of the liver and other viscera (Wells, 1943) and closure of the physiological hernia (Rajfer & Walsh, 1977). These pressures are supposed to cause herniation of the gubernaculum and testis through the ‘weak’ part of the abdominal wall, the inguinal canal (Shrock, 1971). Other propulsive agents that have been suggested are a “peculiar peristaltic intermuscular force” operative in the inguinal canal (Sonneland, 1925), and enlargement of the testis after closure of the internal ring, which forces it to move down the funnel-shaped inguinal canal (Engle, 1932).

Various growth theories have been proposed. Testicular descent has been considered as more apparent than real, with differential growth of the lumbar vertebral column,

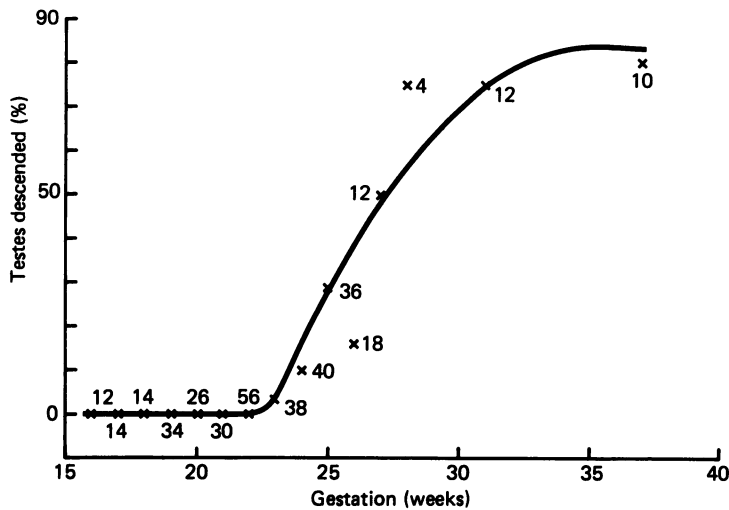


Fig. 1. Correlation between percentage of testes descended and calculated menstrual age of gestation (n = number of testes).

pelvis and abdominal wall being responsible for the testis entering the inguinal canal, while the gubernaculum passively anchors it to the internal ring (Lockwood, 1888; Hart, 1909). Other theories have stressed the downward growth of the processus vaginalis (Cleland, 1856); the penetrating power of unstriated muscle fibres in the gubernacular tip, enabling it to burrow its way downwards, possibly by a process of phagocytosis (Hart, 1909); dilatation of the inguinal canal and scrotum through the uptake of water by hyaluronic acid in the extracellular substance of the gubernaculum (Backhouse, 1964); lengthening of the spermatic vessels and vas deferens, and growth of the scrotum (Hart, 1909, 1910; Keith, 1924; Engle, 1932). The involution theories propose that atrophy, degeneration or shrinking of the gubernaculum brings about testicular descent (Cleland, 1856; Hart, 1910; Rajfer & Walsh, 1977). It has also been suggested that the gubernaculum is not necessary for descent at all (Wells, 1943).

Whatever the mechanical factors at work, there is a large body of clinical and experimental observations suggesting that the process of testicular descent is under hormonal control (Engle, 1932; Wells, 1943). Maternal, placental or fetal pituitary gonadotrophins are thought to stimulate androgen secretion by the fetal testis, with testosterone or one of its metabolites acting in some way to bring about descent of the testis (Elder *et al.* 1982). Another hormone suspected of being active in this regard, is Müllerian inhibiting substance (Donahoe, Ito, Morikawa & Hendren, 1977).

These theories, ranging from the patently logical to the apparently bizarre, have led to much confusion on the topic of testicular descent in the human fetus. At least some of the theories arose because observations made on postnatal or prepubertal descent of the testis in animals (particularly rodents) were extrapolated and uncritically applied to the process of antenatal descent in man, or because the impossibility of experimentation in the human fetus has left the way open for speculation to assume the stature of scientific fact. Also, preconceived notions and prejudices concerning the cause of testicular descent may have influenced the observations recorded by some of the researchers in this field.

In view of the confusion still reigning, it was decided to study the process of testicular descent in the human fetus.

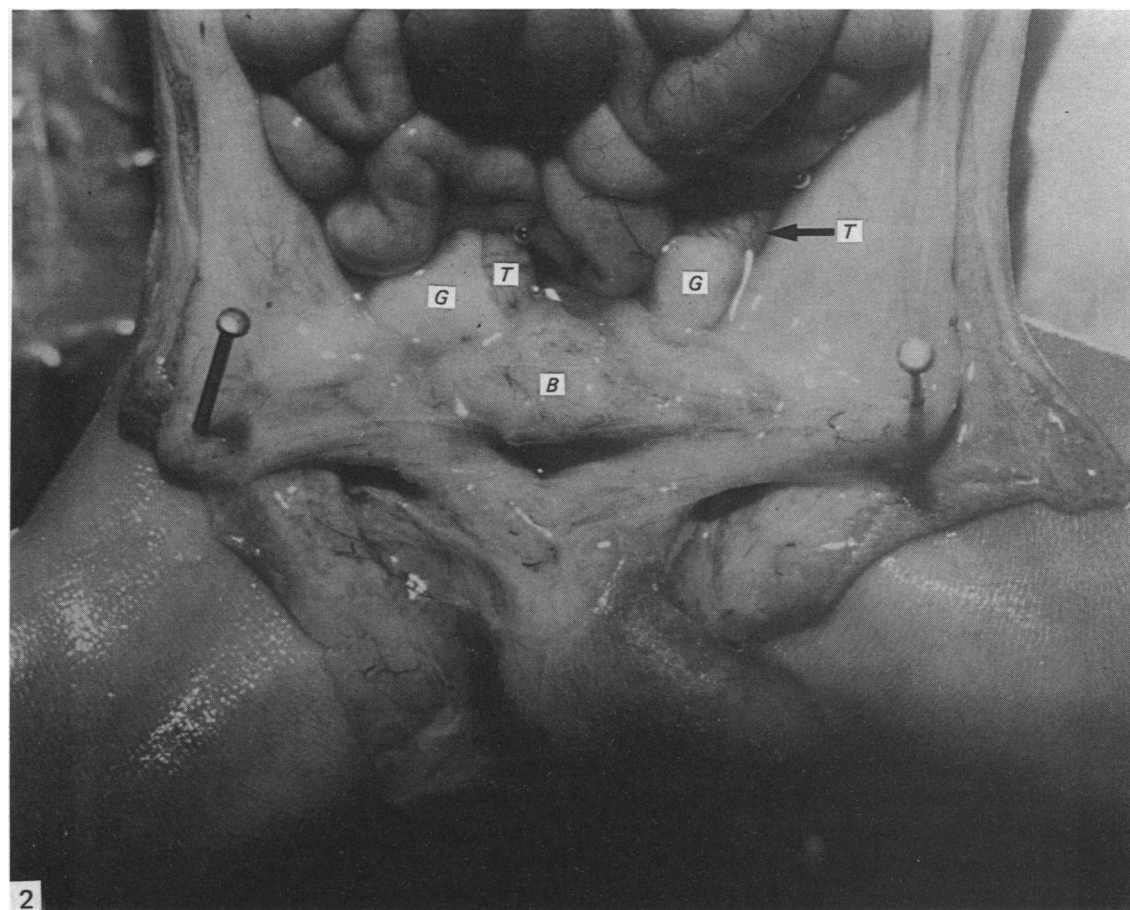


Fig. 2. Human fetus at 22 weeks of gestation (482 g, 195 mm CRL). T, testis; G, gubernaculum; B, bladder.

MATERIALS AND METHODS

Spontaneously aborted human fetuses were obtained from the Department of Obstetrics and Gynaecology, and postmortem dissections of neonates were performed in collaboration with the Departments of Paediatrics and Anatomical Pathology of the Tygerberg Hospital. Consent for the postmortem studies was obtained from the parents of the deceased infants, and approval of the project was granted by the Ethical Committee of the Tygerberg Hospital.

Most of the fetuses were kept at 4 °C and dissected within 24–48 hours, while some were stored at –20 °C and dissected after 1–2 weeks. All dissections were done on relatively fresh specimens, those with severe maceration being rejected from the study. The fetal mass and crown–rump length (CRL) were measured immediately prior to dissection. However, in some fetuses the brain or lungs had been removed for research projects by other investigators, and in these cases the fetal mass or CRL could not be measured.

In view of the unreliability of the date of the last menstrual period for the determination of fetal age, a 'calculated' age of gestation was obtained in the following manner. The fetal mass and CRL were each used individually to derive a gestational

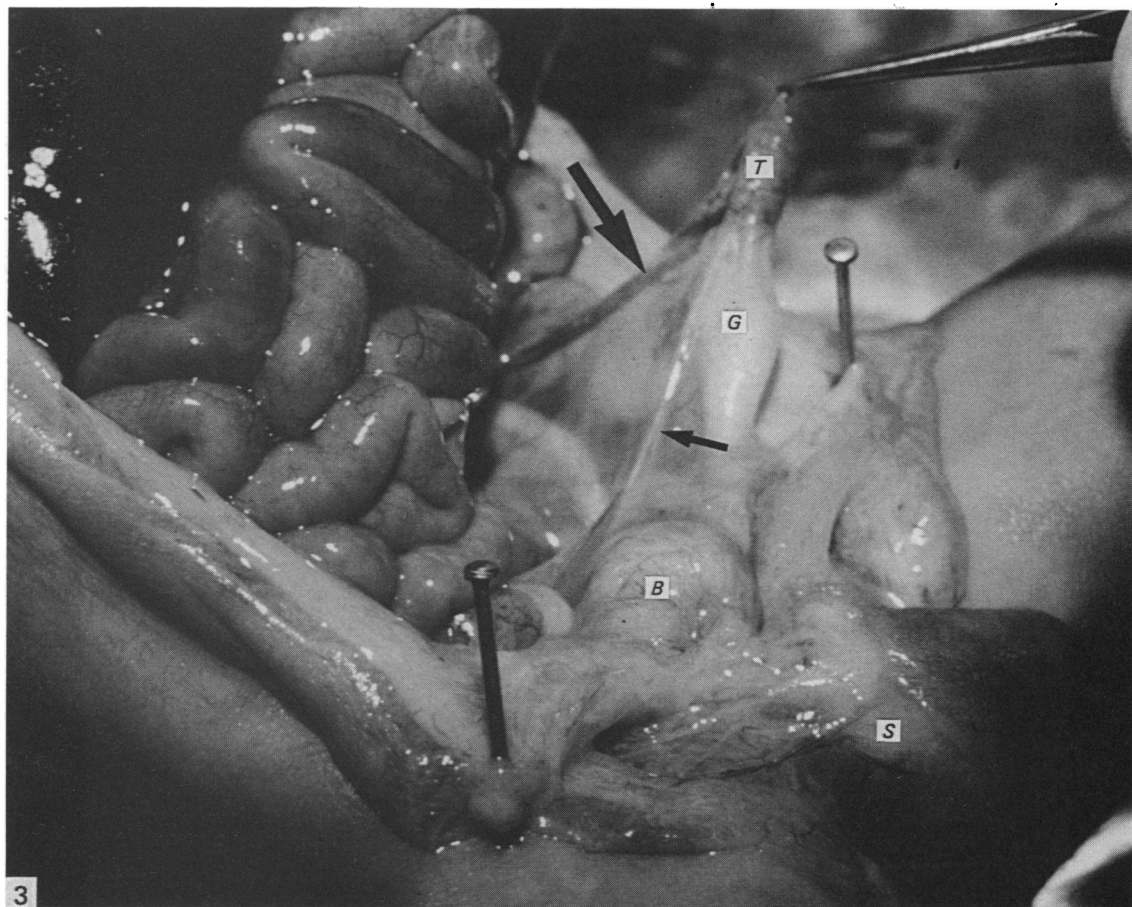


Fig. 3. Human fetus at 22 weeks of gestation. Testicular vessels (large arrow) and vas deferens (small arrow) are enveloped in a fold of peritoneum (mesorchium) which also covers the gubernaculum. T, testis; G, gubernaculum; B, bladder; S, scrotum.

age from curves plotted in a study of 704 human fetuses (Streeter, 1920). These two derived gestational ages were considered together with the gestational age recorded by the attending gynaecologist (based on the date of the last menstrual period or the height of the uterine fundus). When there was ≤ 2 weeks difference between any of the 3, the gestational age was calculated as an average using all values. When there was ≥ 2 weeks difference between any of the 3, the average was calculated using only the two values with the closest concordance. In this way a 'calculated' menstrual age of gestation was obtained. It should be noted that the menstrual age differs significantly from the fertilisation or true age of the fetus, which may also differ from the copulation and ovulation ages (Streeter, 1920).

Tissues from fetuses at representative periods of gestation were preserved in formalin, sectioned and stained for histological study. The testes and gubernacula from all other fetuses were removed for determination of the wet and dry mass. After severance of the spermatic vessels and ductus deferens, the testis and epididymis were separated from the gubernaculum by sharp dissection along a line where the inferior border of the cauda epididymidis was discernible in the gubernacular jelly. In those fetuses with intra-abdominal testes, the inferior tip of the gubernaculum was also freed



Fig. 4. Same fetus as in Fig. 2, with testes picked up in forceps to demonstrate full length of gubernaculum. Arrows indicate testicular vessels in mesorchium. *T*, testis; *G*, gubernaculum; *B*, bladder.

by sharp dissection. The dry tissue mass was obtained by homogenisation in de-ionised water, centrifugation and lyophilisation of the pellet to constant mass at temperature $\leq -50^{\circ}\text{C}$ and vacuum ≤ 200 millitorr.

Using mean values, curves were plotted with the aid of a Hewlett-Packard 9805A calculator. Student's *t*-test was used for determining statistical significance.

RESULTS

In total, 178 male human fetuses and infants were dissected, ranging from 112 to 3980 g in weight, 105 to 380 mm CRL and 15 to 40 weeks calculated menstrual age of gestation.

The testis was regarded as undescended when it was situated superior to the internal inguinal ring and descended when inferior to the external ring. Only one descended testis was found in 126 fetuses < 700 g, with the number of descended testes increasing from 22% in fetuses 700–799 g through 50% in those 1000–1200 g, to 72% in those ≤ 1200 g in weight.

Only one descended testis was encountered in 21 fetuses ≤ 209 mm CRL, with



Fig. 5. Human fetus at 23 weeks of gestation (595 g, 201 mm CRL). Skin over anterior abdominal wall has been removed to reveal inguinal region and interior of scrotum.

descent increasing from 21 % in those of 210–239 mm CRL, through 54 % in those 240–269 mm CRL, to 72 % in those ≥ 270 mm CRL.

Using the calculated menstrual age of gestation, only one descended testis was found in 112 fetuses ≤ 23 weeks, with descent increasing through 10 % at 24 weeks, 50 % at 27 weeks and 75 % at 28 weeks, levelling off to 75 % at 29–33 weeks and 80 % at 34 weeks to birth (Fig. 1).

While situated in the abdomen, the testis lies on top of the white, jelly-like gubernaculum, its weight appearing to compress the gubernaculum somewhat when the fetus is in the supine position. The testis is freely mobile, with no evidence of tension on the spermatic vessels and ductus deferens or on the gubernaculum, and the long axis of the testis may be found to lie at any angle (Fig. 2). When the testis is picked up, the gubernaculum is seen as a cylindrical structure covered by peritoneum on all sides except posteriorly, where the testicular vessels and ductus deferens run in a mesentery (mesorchium) from the retroperitoneal area to the testis (Fig. 3). Macroscopically, the gubernaculum resembles Wharton's jelly of the umbilical cord in appearance and consistency. Its cranial tip is attached to the epididymis and inferior pole of the testis. The caudal end of the gubernaculum enters the internal inguinal ring, where a small fold of peritoneum (the beginning of the processus vaginalis) lies on its anterior aspect (Fig. 4).



Fig. 6. Human fetus at 23 weeks of gestation (538 g, 203 mm CRL). Skin over anterior abdominal wall has been removed. Arrows indicate bulging inferior tip of gubernaculum. Testes are situated in the abdomen. *P*, penis; *S*, scrotum.

Dissection of the inguinal area and scrotum in fetuses < 23 weeks of gestation reveals that there is no macroscopically discernible portion of the gubernaculum caudal to the external inguinal ring (Fig. 5). The scrotum is filled with a small amount of jelly-like tissue. Histologically this tissue resembles the undifferentiated mesenchyme of the gubernaculum, which also fills the inguinal canal, thus creating the impression of a continuous column of mesenchyme reaching from the testis to the scrotum in the early fetus. However, there is no macroscopically defined structure resembling the intra-abdominal gubernaculum distal to the external inguinal ring in fetuses > 100 mm CRL (after 15 weeks of gestation).

When the inguinal canal is opened, it is found to be very short, with the internal and external openings lying almost on top of each other. The canal contains the distal



Fig. 7. Human fetus at 25 weeks of gestation (738 g, 215 mm CRL). Skin over anterior abdominal wall and scrotum has been removed. *T*, testis; *G*, gubernaculum; *P*, penis; *S*, scrotum.

extremity of the gubernaculum, and the fasciae surrounding it may, on dissection, create the impression of attachment to the pubic bone, inguinal ligament, fascia of the thigh and even the scrotum or perineum. However, in some fetuses ≥ 23 weeks of gestation (Fig. 6) it can be clearly seen that the tip of the gubernaculum is bulging through the external inguinal ring and is covered by the fascia superficial to it, with no macroscopically discernible extensions to the scrotum or any other area.

The absence of gubernacular tissue outside the external ring (Fig. 5) was found in most of the fetuses with intra-abdominal testes, while the appearance of the gubernacular tip bulging through the external inguinal ring (Fig. 6) was observed in only 6 of 306 gubernacula (2%) examined in the period 17–26 weeks of gestation. Thus, in the majority of fetuses prior to descent there is no macroscopically discernible



Fig. 8. Same fetus as in Fig. 7. Tip of right gubernaculum picked up in forceps to demonstrate absence of any distal attachment.

extension of the gubernaculum caudal to the external inguinal ring, while in a few there is a noticeable bulging of the gubernacular tip through the external ring.

While the testis is in the abdomen, the distal end of the gubernaculum in the inguinal canal can only be released by sharp dissection of the peritoneum, abdominal wall musculature and fasciae surrounding and covering it. Thus, while the testis is in the abdomen, the gubernaculum may be said to have a firm distal attachment to the region of the inguinal canal. However, once the testis has passed through the canal, the bulbous lower extremity of the gubernaculum is no longer surrounded or covered by firmly adherent layers, nor is it attached to any structure (Fig. 7). The skin can be quite easily lifted off the gubernaculum, and its globular mass is not attached to any structure, nor is it continuous with the small amount of jelly-like material lining the

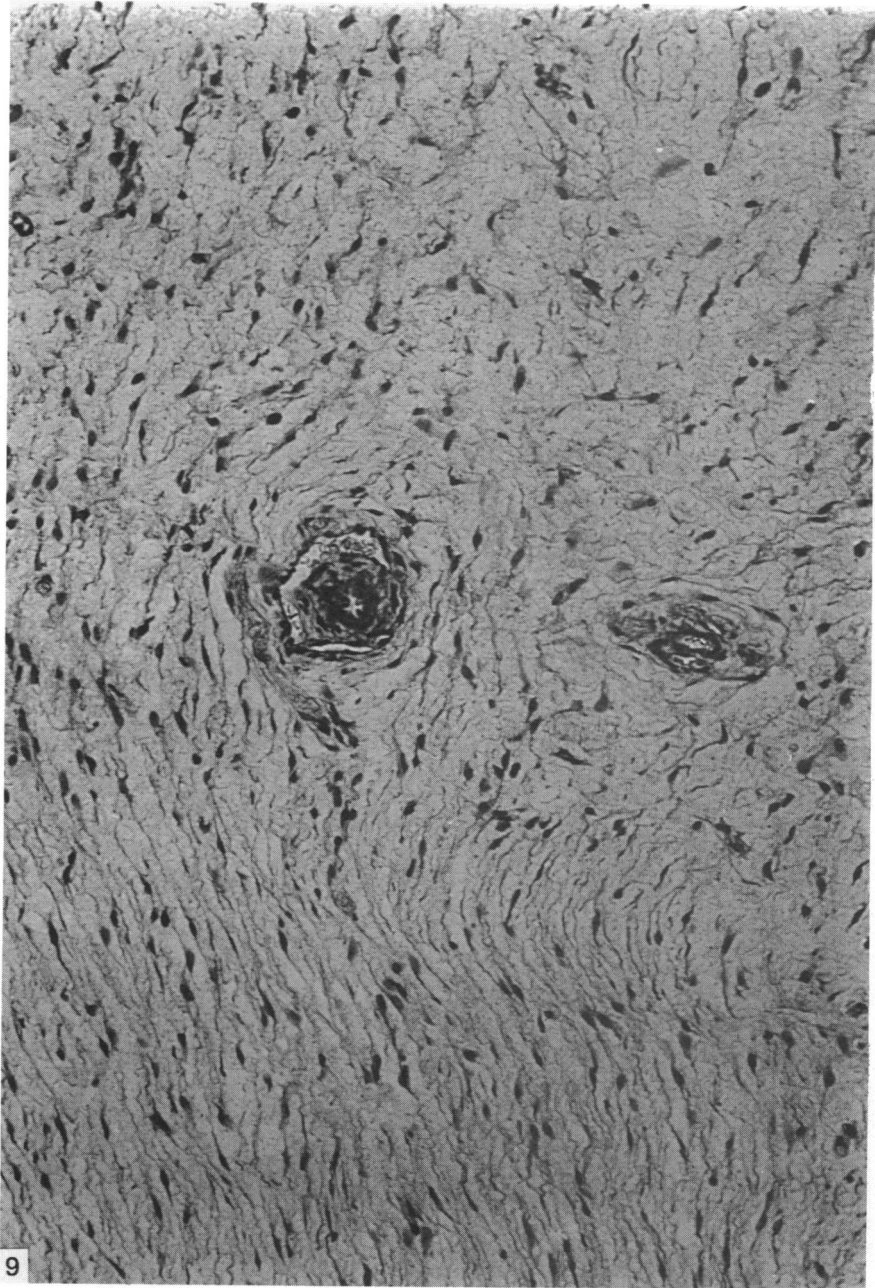


Fig. 9. Gubernaculum of human fetus at 21 weeks of gestation (390 g, 170 mm CRL). Section stained with Alcian blue/periodic acid-Schiff. $\times 150$.

scrotum (Fig. 8). In fetuses where the testis has descended a little lower, the gubernaculum appears relatively smaller, becoming yellowish in colour and more fibrous in consistency. It can still be lifted quite easily out of the scrotum without tearing anything but a few strands of subcutaneous connective tissue.

Histologically the gubernaculum consists of undifferentiated spindle shaped cells with a large amount of extracellular material (Fig. 9). Striated or unstriated muscle



Fig. 10. Section taken from human fetus at 21 weeks of gestation (390 g, 170 mm CRL) demonstrating direct attachment of gubernacular mesenchyme (G) to tunica albuginea of testis (T), with the cauda epididymidis (E) enveloped by the gubernaculum. $\times 40$.

fibres cannot be discerned in this mesenchymatous mass of cells, and even when such fibres can be identified peripheral to the gubernaculum they do not appear to form an important part of the structure when compared to its large bulk of undifferentiated cells. The cranial part of the gubernaculum envelops the coils of the cauda epididymidis, and its mesenchymatous tissue is seen to be in direct contact with the tunica albuginea of the testis itself (Fig. 10). This becomes less obvious in the later stages,

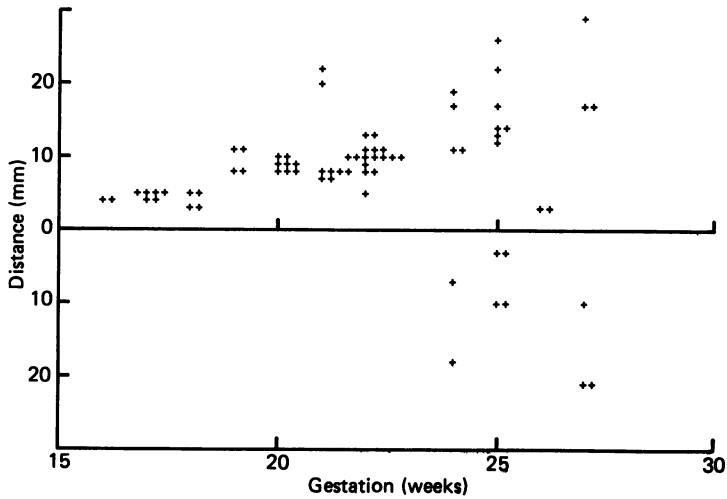


Fig. 11. Distance (in mm) between apex of external inguinal ring and lower pole of testis in 42 fetuses at different periods of gestation. Points (+) represent testes. Above 0-line = superior, below 0-line = inferior to apex of external inguinal ring.

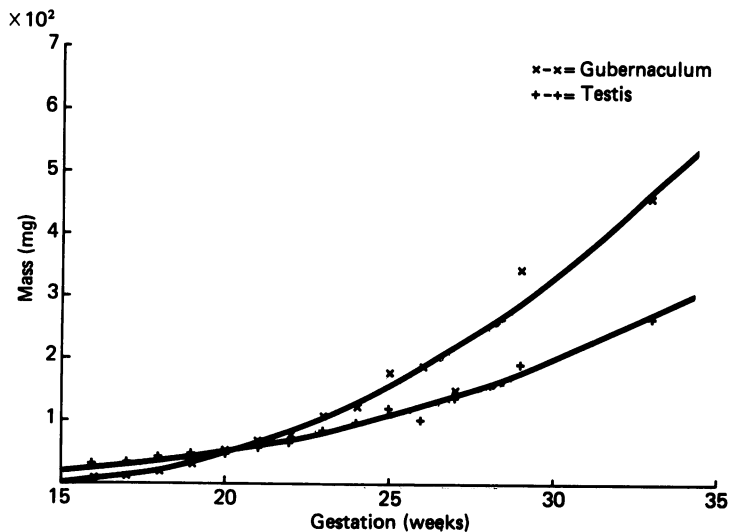


Fig. 12. Absolute wet mass of gubernaculum and testis plus epididymis at different periods of gestation. Points represent mean values.

when proliferation of the caudal coils of the epididymis occurs in the cranial part of the gubernaculum.

Prior to descent of the testis there is an increase in the length of the gubernaculum as measured from the apex of the external inguinal ring to the inferior pole of the testis (Fig. 11). Descent through the inguinal canal is a rapid process, and in only 4 of the 156 testes (2.6%) examined between 23 and 31 weeks of gestation was the testis considered to be in the inguinal canal itself. The gubernaculum, epididymis and testis appear to move through the inguinal canal as a unit, covered on its anterior aspect by the open processus vaginalis. Asymmetrical descent was found in 13 of 78 fetuses (17%) examined between 23 and 31 weeks of gestation. The left testis had descended

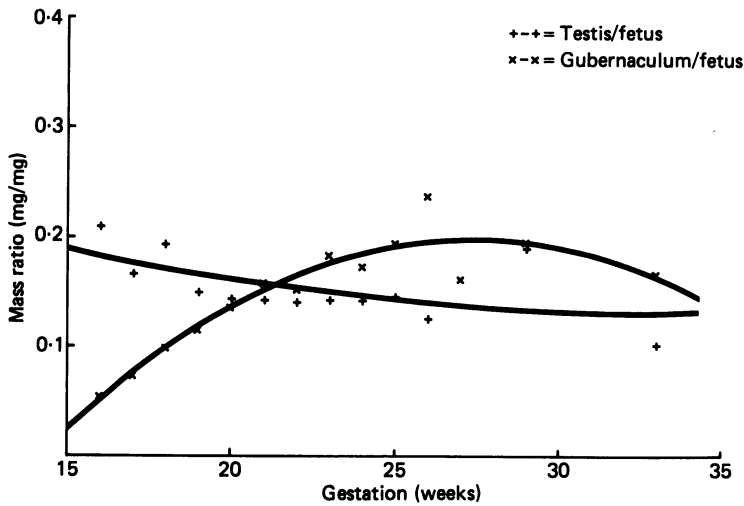


Fig. 13. Relative wet mass of gubernaculum and testis plus epididymis at different periods of gestation. Relative wet mass = mass of organ (mg)/mass of fetus (g). Points represent mean values.

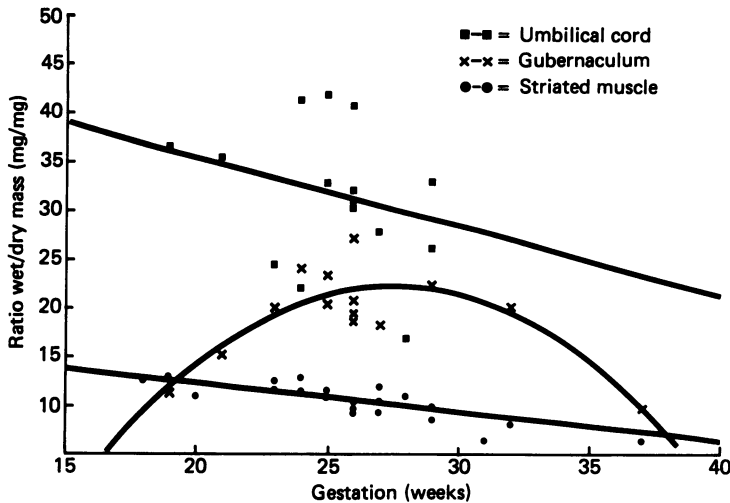


Fig. 14. Ratio of wet/dry mass (mg/mg) of umbilical cord, gubernaculum and striated thigh muscle at different periods of gestation. Points represent mean values.

prior to the right in 9 of the 13 cases (70%). In fetuses with asymmetrical descent, the gubernacula of descended and undescended testes showed no significant difference in wet mass relative to the fetal mass. Non-descent occurred more commonly on the right: in 15 cryptorchid fetuses, 11 of the 17 undescended testes (65%) were on the right side.

The absolute wet mass of the gubernaculum exceeds that of the testis plus epididymis during and after the period of descent, while the absolute wet mass of both increases rapidly (Fig. 12). However, when the wet mass of the organs is calculated as a ratio relative to the mass of the fetus, the relative wet mass of the gubernaculum increases significantly ($P < 0.01$) prior to descent and decreases slightly in the period after descent, while the relative wet mass of the testis and epididymis remains fairly constant or even decreases slightly prior to and during the period of descent (Fig. 13).

Calculation of the wet/dry mass ratio of the gubernaculum shows a significant increase ($P < 0.01$) prior to, and a decrease after, descent of the testis. This increase in the wet/dry mass ratio denotes an increase in the water content of the gubernaculum. In contrast, the wet/dry mass ratio of the umbilical cord and thigh muscle tissue shows no increase during the period of testicular descent (Fig. 14).

DISCUSSION

The controversy about the mechanism of testicular descent appears to be kept alive by the conflicting observations of various investigators in this field. The differences seem to revolve around three issues: (1) the cranial and caudal attachments of the gubernaculum, (2) the type of cell forming its 'active' constituent and (3) the changes that take place in the gubernaculum and its surrounding structures during testicular descent.

Regarding the attachments of the gubernaculum, the present study confirms the observation of Hunter (1841) that it is "firmly fixed to the lower parts of the testis and epididymis, and to the beginning of the vas deferens". Scorer (1962) stressed the "very substantial" attachment of the gubernaculum to the testis itself, while noting that "the lower pole of the epididymis disappears into the gubernaculum below the testis". These observations are supported by most of the investigators in this field.

However, Hart (1909, 1910), Wyndham (1943), Wells (1943) and Hadžiselimović & Krüslin (1979) emphasised that the gubernaculum is attached to the epididymis and thus only indirectly to the testis. Hadžiselimović (1983) referred to Bramann's statement that testicular descent cannot take place in the absence of the epididymis, because of the inability of the gubernaculum to exert traction on the testis while being directly inserted into the epididymis. He postulated that peristaltic motion and secretory activity of the epididymis "develops a stronger pressure at the center of gravity and helps to change the position of the epididymis and passively the position of the testis, as the latter is carried by the epididymis".

The present study does not support this emphasis on the epididymal attachment of the gubernaculum. Denying the testicular attachment may serve to explain those cases of cryptorchidism with epididymal detachment or descent in advance of the testis. However, it is difficult to conceive how peristaltic and secretory activity of the epididymis, by increasing pressure at the 'center of gravity', can bring about testicular descent. Gravity cannot play a significant role, since descent takes place during a period when the majority of fetuses are lying in a vertex presentation. It remains an unresolved question whether the high incidence of testicular and epididymal abnormalities are a cause or a result of the cryptorchid condition (Mininberg & Schlossberg, 1983).

The present study does not support the finding of multiple distal attachments of the gubernaculum to the saphenous area, pubis, root of the penis, scrotum and perineum as described by Lockwood (1888), Hunter (1926), Wyndham (1943), Lemeh (1960) and Schechter (quoted in Rajfer & Walsh, 1977). Backhouse (1981) re-examined the original Lockwood dissection in the Anatomy Museum of St Bartholomew's Hospital and came to the conclusion that what Lockwood had dissected was the developing peripheral fascia around the gubernaculum. However, the existence of the 'tails of Lockwood' has been mentioned in many standard textbooks, and Rajfer (1986) even describes the 'five branches' of the gubernaculum as going not only to the perineum, femoral canal, superficial inguinal pouch and suprapubic area, but also to the opposite scrotal compartment – an observation certainly not recorded by Lockwood.

The present study confirms the observations of Cleland (1856), Wells (1943), Scorer

(1962) and Hadžiselimović (1983) that there is no extension of the gubernaculum into the bottom of the scrotum. As described by Cleland (1856), the bulbous extremity of the gubernaculum is contained in a fascial pouch around the external inguinal ring, and is "only attached to the walls of the pouch by more or less dense cellular tissue". Backhouse (1964, 1981) emphasised that the abdominal wall muscles and inguinal canal differentiate around the mesenchymatous core of the gubernaculum. In the early fetus there is a continuous column of mesenchyme extending from the testis to the scrotum. However, from about the 100 mm CRL stage (16 weeks) the distal end of the gubernaculum becomes "contained in a differentiated pocket of the scrotal wall" and later on, with the marked increase in the gubernacular bulk, it loses its attachment to the scrotal floor (Backhouse, 1981). Although his photomicrograph from a 23 mm CRL embryo demonstrates continuity of the mesenchymatous tissue from the gubernaculum to the region of the future scrotum, the photomicrographs from a 163 mm CRL fetus do not show convincing extension of the gubernaculum beyond the superficial fascia around the external ring (cf. Figs. 2-1, 2-4 and 2-5, Backhouse, 1981).

The present study confirms the existence of a preformed inguinal canal containing the tip of the gubernaculum as described by Hart (1909) and Backhouse (1964). This refutes the theory of Carus & Cloquet (quoted by Curling, 1840) that the testis herniates through the abdominal wall, carrying the various layers with it to form the coverings of the testis and cord. The tip of the gubernaculum does extend through the superficial inguinal ring, but in fetuses between 15 and 22 weeks of gestation no macroscopically discernible extension of the gubernaculum into the scrotum was noted in the present study.

Descriptions of the type of cell forming the 'active' constituent of the gubernaculum seem to have been influenced most by preconceived notions about the mechanism of descent. Hunter (1841) stated that "in the human foetus, while the testis is retained in the cavity of the abdomen, the cremaster is so slender that I cannot trace it to my own satisfaction, either turning up towards the testis or turning down towards the scrotum". However, Curling (1840) described a layer of well developed striated muscle fibres ascending from the deep inguinal ring to the testis, and stated that during descent "the muscle of the testis is gradually everted". Cleland (1856) observed some striated muscle fibres, but denied that these were attached to the testis or formed an intrinsic part of the gubernaculum.

Lockwood (1888) described the main bulk of the gubernaculum as made up of round and spindle shaped cells that "have a decided likeness to unstriated muscular tissue". He suggested that "the chief labour of transition falls upon the smooth muscular elements of the cremaster", possibly assisted by the striped muscle fibres. Although unstriated muscle in the gubernaculum has been observed by several other investigators, Wells (1943) and Tayakkanonta (1963) denied the presence of smooth muscle fibres.

Hunter (1841) described the gubernaculum as 'vascular and fibrous', with the fibres running in the direction of the gubernaculum itself. However, Wyndham (1943) found very little connective tissue and rejected the theory of Meckel that the testis is pulled down by scar contracture of the gubernacular fibres. Lockwood (1888), Wells (1943) and Tayakkanonta (1963) found embryonic or mucoid connective tissue in the gubernaculum, and Lemeh (1960) noted young mesenchymal cells. However, Backhouse (1964) was the first to emphasise the totally undifferentiated, mesenchymatous nature of the gubernaculum, with its large amount of extracellular material containing glycosaminoglycans (acid mucopolysaccharides). The present study confirms this observation. The spindle shaped cells of the undifferentiated mesenchyme with its

"decided likeness to unstriped muscular tissue" probably led Lockwood (1888) to assume that smooth muscle pulls the testis down. Although the presence of striated muscle fibres around the distal part of the gubernaculum cannot be denied, the present study does not support the theory (Curling 1840) that traction by, or eversion of, the cremaster causes descent of the testis.

With regard to the changes in the gubernaculum and its surrounding structures, Lockwood (1888), Wyndham (1943) and Backhouse (1964) observed that in the early fetus the position of the testis relative to the acetabulum remains constant, and suggested that the separation between the testis and kidney is caused by growth of the lumbar spine and pelvis. The present study shows a marked increase in the length of the gubernaculum prior to descent. This has been noted previously by Lockwood (1888) and a number of other investigators. The present study also confirms the observation of Lockwood (1888) and others that an increase in the length of the testicular vessels and ductus deferens occurs prior to descent. The testis lies freely in the abdomen, without any tension on the vessels or gubernaculum. With the fetus in the supine position, the weight of the testis resting on the gubernaculum compresses it somewhat. However, the tortuous appearance of the gubernaculum is merely an effect of gravity, and disappears when the testis is picked up or the fetus is held upside down. It does not provide evidence of an elevated intra-abdominal pressure being exerted on the testis, as suggested by Elder *et al.* (1982).

The present study provides gravimetric proof that the absolute and relative wet mass of the gubernaculum increases rapidly prior to the period of descent. The absolute wet mass of the gubernaculum exceeds that of the testis plus epididymis. Backhouse (1964) ascribed the increase in the bulk of the gubernaculum to an increase in the extracellular material and to the uptake of water by the hyaluronic acid component of the extracellular glycosaminoglycans. He suggested that this may serve to dilate the inguinal canal and scrotum, thus facilitating descent of the testis. The present study shows an increase in the wet/dry mass ratio (i.e. water content) of the gubernaculum, which is not found in the fetal striated muscle or umbilical cord tissue. However, it remains to be established whether this is an extra- or intracellular accumulation of water. Cellular hyperplasia and hypertrophy may be equally or more important causes of the increase in the size of the gubernaculum (Heyns, Human & De Klerk, 1986).

The present study provides photographic evidence that prior to descent the tip of the gubernaculum bulges through the external inguinal ring. The fact that this appearance was seen in only a few fetuses may be explained by presuming that it is a rapidly developing and transient phenomenon. Wensing (1968) noted that the expansion of the extra-abdominal part of the gubernaculum which he had observed in animal fetuses is similar to the inflation of a balloon with its neck enclosed in a restricted passage while the fundic part lies free, and suggested that this can exert traction on the intra-abdominal testis by the force of its expansion. However, Hadžiselimović (1983) denied that any balloon-like swelling or expansion of the gubernaculum outside the inguinal canal takes place.

Prior to descent the gubernaculum is firmly attached to the region of the inguinal canal, but once the testis has passed through the canal the gubernaculum no longer has any firm distal attachment to any structure, nor does it extend to the bottom of the scrotum. Keith (1924), Hunter (1926), Wyndham (1943) and Scorer (1962) also found that after descent the attachment of the gubernaculum to the scrotum is extremely tenuous.

In the present study 75 % of the testes passed through the inguinal canal in the period between 24 and 28 weeks (calculated menstrual age of gestation). Previous investigators

placed the time of descent variously at the beginning of the 7th month (Wyndham, 1943), about the 8th month (Hunter, 1841) and at the beginning of the 29th week (Lemeh, 1960). Birnholz (1983) in an ultrasound study of intrauterine fetuses found 62% of testes descended between 28 and 30 weeks (fertilisation age of gestation); with 93% descended after 32 weeks. The 20% incidence of cryptorchidism after 34 weeks found in the present study may be attributed to the fact that only aborted fetuses and prematurely deceased infants were dissected.

Wyndham (1943) found descent to occur between 230 and 240 mm CRL. Scorer (1962) noted descent in 38% of fetuses between 900 and 1800 g and in 82% between 1800 and 2500 g. In the present study 54% of testes descended between 210 and 270 mm CRL, which correlated with a fetal mass of 700–1200 g.

Scorer (1956, 1964) noted that descent takes place a little later on the left than on the right. However, in the present study the left testis had descended prior to the right in 70% of the cases with asymmetrical descent. Scorer also noted a slight preponderance of cryptorchidism on the right, which is in agreement with the findings of the present study (65% of cryptorchid testes were situated on the right).

Wyndham (1943), Scorer (1962) and Backhouse (1964, 1981) found that descent of the testis is normally rapid. Scorer estimated that it takes only a few days or possibly 2 or 3 weeks. The present study shows that, although the majority of testes pass through the inguinal canal within a period of 4 weeks, descent of the individual testis probably occurs much more rapidly since the testis was situated in the inguinal canal itself in only 4 of the 156 testes (2.6%) examined in the period of descent. This rapid passage of the testis through the inguinal canal may be explained by increased intra-abdominal pressure (e.g. fetal respiratory movements or hiccuping) which is transmitted via the open processus vaginalis to the tip of the gubernaculum. However, there is no reason to suppose that this pressure is higher in the male than in the female fetus, yet descent of the ovary does not occur. Also, an elevated intra-abdominal pressure would exert equal force on both testes, which does not account for the 17% of asymmetrical descent noted in the present study. The facts appear to indicate that gubernacular swelling plays the central and most important role in testicular descent. However, it remains speculative whether the expansion of the gubernacular tip outside the inguinal canal provides traction on the testis or is merely the result of the testis and gubernaculum moving as a unit through the canal.

There has been some controversy about the changes which take place during descent of the testis. Hunter (1841), Cleland (1856) and Backhouse (1964) noted enlargement and active distal growth of the processus vaginalis, and the present study confirms this observation. Cleland (1856) stated that as the testis descends the gubernaculum "assumes a shrivelled appearance, as of a body undergoing atrophy". He concluded that descent is independent of mechanical action and is brought about by a growth process, marked by atrophy of the gubernaculum in front of the descending testis and growth of the processus vaginalis behind it. Shortening of the gubernaculum during descent was also noted by Lockwood (1888) and several other investigators. However, Keith (1924) and Scorer (1962) stated that during transit of the testis the gubernaculum retains the same length.

Backhouse (1964, 1981) noted an increase in the bulk of the gubernaculum during descent, and postulated that this may serve to dilate the inguinal canal and scrotum. He rejected the assumption of Rajfer & Walsh (1977) that "during the actual event of testicular descent the gubernaculum that is in contact with the testis degenerates, thus allowing the testis to migrate along the pathway of the disappearing gubernaculum".

The present study supports the observation of Scorer (1962) that the testis, epididymis and gubernaculum move through the inguinal canal as a single entity. During the period of descent the absolute wet mass of the gubernaculum exceeds that of the testis plus epididymis. However, the relative wet mass and wet/dry mass ratio (water content) of the gubernaculum, which increase significantly prior to descent, remain fairly constant during the period of descent. The present study does not support the observation of Hart (1909, 1910) that disproportionate growth of the inguinal canal effects not so much a descent of the testis as an ascent of the inguinal canal.

Hunter (1841) noted that after its passage through the external inguinal ring the testis "only by degrees descends to the bottom of the scrotum". This observation is supported by Scorer (1962), Backhouse (1981) and by the present study. Hunter (1841) noted that the gubernaculum after descent is "shortened and compressed", while Curling (1840) observed that it contributes to the loose cellular tissue of the scrotum and "gradually wastes away". Shrinking, involution and eventual disappearance of the gubernaculum after descent has been noted by virtually all the investigators. Backhouse (1981) found a reduction in the intercellular fluid and Hadžiselimović (1983) noted an accumulation of collagen in the gubernaculum. The present study confirms that after descent the gubernaculum becomes smaller and appears more fibrous, while there is a decrease in its relative wet mass and its wet/dry mass ratio (water content). This involution of the gubernaculum may facilitate descent of the testis inferior to the external ring, but in the absence of any firm distal attachment of the gubernaculum it cannot provide significant traction.

The present study confirms the observations of Wald & Scammon (1931), Wyndham (1943) and Lemeh (1960) that, although the absolute size of the testis and epididymis increases, the size of the testis relative to that of the fetus remains constant or even decreases slightly prior to and during descent. Wells (1943) noted that, if gonadotrophins induce descent as a result of androgen secretion by the fetal testis, one would expect rapid testicular growth during the period of descent. The fact that the testis does not increase in size relatively faster than the fetus as a whole (while the gubernaculum does) is contrary to the theory of Engle (1932) that rapid growth of the testis after closure of the internal ring would propel it down the funnel shaped inguinal canal into the scrotum. To date, no investigator has been able to detect the presence of an androgen receptor in the gubernaculum of any species (Rajfer, 1986), and the difference in the growth patterns of the testis and gubernaculum raises the possibility that some unidentified gubernaculotrophic hormone may mediate descent of the testis (Heyns *et al.* 1986).

The present study indicates that the increase in the size of the gubernaculum plays the central and most important role in testicular descent. Although growth of the processus vaginalis, lengthening of the vas deferens and testicular vessels, and enlargement of the scrotum are also essential, the marked increase in the size of the gubernaculum is such a conspicuous feature that its importance can hardly be denied. However, it remains speculative whether this causes mechanical dilatation of the inguinal canal and scrotum or exerts forceful traction on the testis. It may be merely a growth process which prevents closure of the inguinal canal by the differentiating muscle layers, or it may simply provide a structure for the transmission of intra-abdominal pressure via the open processus vaginalis, thus directing the course along which the testis is propelled.

To conclude, fetal descent of the testis may conveniently be divided into 3 phases: (1) an apparent internal descent in the early embryo, caused by differential growth of the lumbar vertebral column and pelvis, (2) passage of the testis through the inguinal

canal, a rapid process in which the gubernaculum seems to play the most important role and (3) descent of the testis from the external inguinal ring into the scrotum, which is a more gradual process.

Testicular descent in older children, which can be induced by hormonal stimulation at a time when the gubernaculum no longer exists in its fetal or neonatal form, is probably due to pubertal hypertrophy of the testis and scrotum coupled with lengthening of the testicular vessels and ductus deferens, rather than to any process comparable to antenatal descent (Backhouse, 1981).

SUMMARY

This study of 178 male human fetuses and infants demonstrates that descent of the testis through the inguinal canal is a rapid process, with 75% of testes descending between 24 and 28 weeks of gestation. The gubernaculum is a cylindrical, gelatinous structure attached cranially to the testis and epididymis. While the testis is in the abdomen, the caudal tip of the gubernaculum is firmly attached to the region of the inguinal canal. In a few fetuses prior to descent the globular tip of the gubernaculum can be seen bulging through the external inguinal ring, covered by superficial fascia, with no macroscopically discernible extensions to the scrotum or any other area. Once the testis has passed through the inguinal canal, the bulbous lower tip of the gubernaculum is no longer firmly attached to any structure, nor does it extend to the bottom of the scrotum.

Histologically the gubernaculum consists of undifferentiated mesenchymatous tissue. Prior to descent of the testis, there is an increase in the length of the intra-abdominal gubernaculum. The wet mass of the gubernaculum relative to the fetal mass increases rapidly prior to descent, while the relative wet mass of the testis remains constant during this period. There is also an increase in the wet/dry mass ratio of the gubernaculum, denoting an increase in its water content prior to descent. This indicates that a combination of growth processes is responsible for testicular descent, with the increase in the size of the gubernaculum playing the most important role in passage of the testis through the inguinal canal.

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